SIR AMBROSE FLEMING
(Jubilee of the Valve)

By J. T. MacGregor-Morris

(*Plate 6*)

NOVEMBER of last year (1954) saw the fiftieth Anniversary of the invention of the radio valve. It is fitting therefore to recall the life and work of its originator, John Ambrose Fleming, particularly stressing the way in which his work, converging in many fields, prepared him to make the invention, by which his name is best known.

Ambrose was born at Lancaster on 29 November 1849, the eldest of seven children. His father, the Rev. James Fleming, was minister of High Street Congregational Chapel in Lancaster for eight years from August 1845. The family moved to London in 1854 when he became minister of Kentish Town Congregational Chapel, which position he held until his death in 1879.

His grandfather on the mother's side was John Bazley White, of Swanscombe, Kent, who had a large family of sons and daughters. He was a pioneer in the manufacture of Portland cement. From him Ambrose may have inherited something of his original turn of mind, for early in this century Mr White built his own house entirely of cement. One of his mother's sisters became well known later as the founder of the Ranyard Mission.

Early in his life Ambrose exhibited a mechanical turn of mind, interested in things rather than persons. When about ten years old he went to a private school for boys where he found the geometrical drawing lessons of absorbing interest. At eleven years of age, he had set up his own workshop at home, where he made models of engines and ships. Ambrose entered University College School, Gower Street, in 1864 where he did well in mathematics, but was at the bottom of the classes in Latin. In spite of this he passed the London Matriculation when only 17 years old.

Entering University College in 1867 he studied physics under G. Carey Foster and mathematics under de Morgan. After two years at College he had to leave in order to replenish the exchequer. He then tried to gain practical experience with a Dublin firm of shipbuilders. This turned out to be a failure, for the work was only that of tracing drawings, so he left after three or four

SIR AMBROSE FLEMING, Kt., M.A., D.Sc., F.R.S.

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months. For the next two years Fleming acted as a clerk to a stock jobbing firm on the London Stock Exchange, rather an unusual step in the training of an engineer. As the hours were easy, the work finishing at four o'clock, he decided to take this opportunity to complete his studies for the B.Sc. degree during the evenings. So thoroughly did he use this opportunity, that of the only two candidates in the first division, Fleming was one.

Having taken his B.Sc. in 1870, the following year he obtained, through Dr Frankland's influence, a post as Science Master at Rossall School. He was successful in this but after 18 months decided he needed a higher training in scientific work. Returning to London at the age of 23 he came to study advanced chemistry under Frankland at the Royal School of Mines, South Kensington, and in 1874 was appointed to take some share in the teaching work of the Advanced Chemical Laboratories. There is ample evidence that his work was much appreciated.

During the same period Fleming devoted much time to the study of the chemistry of the voltaic cell, and Professor Guthrie, asked him to collaborate in the analysis of the gas which was driven off the plates in an electrolytic cell.

We now arrive at another turning point in Fleming's career, that in which he turns from chemistry to physics and its practical applications. Here his work with Dr Guthrie appears to have been the deciding factor. Dr Guthrie was, at that time, experimenting with electrically charged bodies raised to a red-heat. A fuller account of this work will be reserved until later.

After two sessions, as funds were once more depleted in 1874, Fleming took a post as Science Master at Cheltenham College. Here he introduced a more practical method of teaching on the lines of Dickens's Mr Squeers. 'When a boy has spelt "Winder" he goes and cleans it—in fact we allow the boys to see and do the things about which they are learning.' In both the Rossall and Cheltenham posts he developed his method of teaching in which experimental illustrations took a large part.

A few months earlier the Physical Society of London was founded mainly through the action of Professor Guthrie. The inaugural meeting was held in his lecture-room on 12 March 1874, in the Science Schools, South Kensington. He gave to Fleming the honour of reading the first paper, which was 'On the new contact theory of the galvanic cell'.*

While still at Cheltenham College he had been following the work of James Clerk Maxwell, that famous physicist who in 1873 published his two volume book on *Electricity and magnetism*. This book, which after eighty years

* J. A. Fleming, B.Sc., F.C.S. 21 March 1874. *Proceedings Physical Society of London*, 1. 1,

is still regarded as a classic, has left an imperishable mark on the pages of science.

In 1875 Fleming was already corresponding with Clerk Maxwell and soon made the decision that he must go to Cambridge to study under him. After an attempt to read this book he realized how far behind his own mathematics were and that a great deal of study would be required before he would be able to take full advantage of Maxwell's lectures. During his first six months as an undergraduate he made great efforts to remedy this.

Method of training to be an engineer

When quite a boy Fleming had wanted to become an engineer. But as the eldest of a family of seven, obviously he could not hope to become a premium pupil to a professional engineer on account of the expense involved.

He did not give up his aim, but attained it by a method which although arduous was effective in the long run. He sandwiched, as we shall see, training and earning right up to the time when he became Professor of Physics and Mathematics in Nottingham University College.

Going to Cambridge

At the age of 28, October 1877 saw him at Cambridge realizing his fixed determination to study under Clerk Maxwell. In the Cavendish Laboratory which had been founded by Clerk Maxwell, Fleming worked under Dr William Garnett. On Clerk Maxwell's advice he checked the standard coils of resistance and found them $1\frac{1}{2}$ per cent. too small. For the purpose of these measurements Fleming devised an improvement of the Carey-Foster Bridge for accurate and at the same time quick use. As the measuring wire was arranged in the form of a nearly complete circle, and the rest of the connexions along an arm, its peculiar shape caused Maxwell to dub it Fleming's banjo.

From this time dates his interest in standards. In relation to Maxwell's lectures Fleming took full notes, although this was not easy. He wrote them up and much later in 1931 presented them to the Cavendish Laboratory.

As a young man he avoided most social occasions and when he went to St John's he chose to live outside the College that he might give his time to uninterrupted study.

In November 1879 both Clark Maxwell and his own father died.

The following year Fleming took his D.Sc., London—a rare degree in those days—and in 1883 his College elected him Fellow. Forty-four years later he was to receive the honour of an Honorary Fellowship.

His paper before the Institution of Electrical Engineers in 1885 (*Jour. Soc.*

Telegraph Engineers and Electricians 1885, **14**, 488) was outstanding. It was on the need for a national standardizing laboratory for electrical instruments and is acknowledged to have originated the movement which resulted in the establishment of the Board of Trade Electrical Laboratory. Major P. Cardew was its first director. Later in order of time came the German Physikalisch Technische Reichsanstalt, and then our own N.P.L. and its French equivalent.

Returning to the Cambridge days, after one year's work as demonstrator in mechanism in Cambridge, the choice of a first Professor of Physics and Mathematics at University College, Nottingham, fell on Dr Fleming. The attraction of London, however, proved too strong, and before the year was out he left.

Through his cousin Mr Arnold White, who was its secretary, the Edison Telephone Company offered him the post of consultant. About this time the London Telephone Company had been formed. Litigation followed because the Post Office claimed a monopoly not only for telegraphy but also for telephony, then in its infancy. The dispute was decided in favour of the Post Office and Fleming became adviser to the London National Company.

He took on at this time added responsibility as adviser to the Swan Lamp Factory and the next year Professor Carey Foster of University College, feeling the need of some teaching in the then new subject of electrical engineering, advised the College Council to ask Dr Fleming to give a short course of lectures on the subject, and the following year Fleming was offered the first Professorship of Electrical Engineering at University College, London, this was in 1885.

Here Professor, or Dr Fleming as he desired to be known at that time, found plenty of scope for development; the sole apparatus was, as he described it, 'a black-board and a piece of chalk!' He was given a small room as laboratory and a grant of £150 and soon started a photometric laboratory and arranged for his students to visit various works.

His lectures on electrical technology were well thought out, and would often be illustrated by a single appropriate experiment, rigged up beforehand by himself. He was careful in his definitions, and strongly objected to looseness of language in answers to examination papers. I once heard him say as early as 1895 he considered that all engineering students should take a paper in English in the finals for the B.Sc. degree. Many students found it difficult to take proper notes, for, although his diction was clear and crisp, his delivery was exceedingly rapid.

For many years Dr Fleming's only fixed engagement at the College was his one hour's lecture (on electrical technology) from 11 to 12 noon on

Fridays. This arrangement held for at least a dozen years and as a consequence he was able to undertake much outside consulting work, as well as lecturing for the Gilchrist Trust and giving other popular science lectures in the provinces. Although in some ways this was beneficial to his students it had also disadvantages. Not unnaturally, as time went on, pressure for further teaching came from his senior students, and from other quarters, and in response he added a course of lectures on advanced electrical technology.

What, it may be asked, was the equipment of the laboratory during the first ten years? Well, between 1891 and 1894 when, my brother (the late Dr D. K. Morris) and I were students, Dr Fleming's department consisted of a laboratory, only twenty feet square, at the top of the building. This included his desk and some apparatus—most of which had been either given or lent by professional friends. In addition in the basement there was a 25-cell battery of accumulators, and a gas-driven dynamo of Crompton, which was used to charge the battery.

Much of the experimental work undertaken by his students was done after College hours either at a sub-station of the London Electric Supply Corporation (under the Adelphi Arches) near Charing Cross or at the Royal Institution between the hours of 5 p.m. and 10 p.m. Part of this time the author acted as his assistant for a period of four years.

Transformer tests

We shall now follow more closely some of Fleming's achievements during this period of 40 years. From 1885 to 1895 Fleming was one of the leading exponents of the theory of alternating current transformers, and of their practical performance, the two volume treatise which he wrote on *The alternate current transformer* being for many years the premier treatise on the subject. In one of his diaries he states that this book was written in its entirety after 10 o'clock at night.

In 1890 Fleming was engaged on an almost classical investigation on the behaviour of power transformers under various conditions of load. That we may understand the difficulties of making reliable measurements of alternating voltage, current and power, we should recall the fact that the only trustworthy instruments available at that time for such purposes were the Cardew Hot-Wire Voltmeter and the Siemens' Electrodynamometer, apart from the Kelvin Electrostatic Voltmeter and the Kelvin Ampère balance. The wattmeter for alternate current measurements of power was hardly existent, and the importance of reducing the inductance of the shunt circuit of the wattmeter in comparison with its resistance, when the load was highly

inductive, was only beginning to be appreciated by practical men. In fact, Fleming and Swinburne actually constructed their own wattmeters, and even then such men had to check laboriously their results by the 3-voltmeter method, which requires a supply giving about double the working voltage of the transformer, a condition not always easy to obtain.

During the work on these transformers the development of the instruments and the low voltage part of the testing was done at University College, but by far the greater part was carried out at a sub-station of the London Electric Supply Corporation. At this time Mr J. C. Shields was Dr Fleming's assistant, and he spared no pains to ensure that the results were reliable. The experiments extended over a period of five months.

All the results were collected in a paper entitled 'Experimental researches on alternate current transformers', which Fleming presented to the Institution of Electrical Engineers in November 1892. The paper excited great discussion. The presentation of the paper, and the discussion occupied five consecutive Thursday evenings, and it was not until 9 February 1893, that Fleming was allowed to reply, and he took the whole evening to do this.

Undoubtedly this paper and the discussion which it evoked was a great contribution to the subject.

He did not let the grass grow under his feet, for as a result he delivered four Cantor Lectures to the Society of Arts on 'Practical measurements of alternating currents' and these were illustrated fully by experiment. Later on he was asked to direct and arrange to carry out further experimental investigations, this time for the City of London Electric Lighting Company on the ageing-of-core losses in transformers, and later, on the waveform of the alternators at Bankside on open circuit and when on load.

Fleming's mastery of the underlying principles combined with a rare gift for exposition, ensured that practical men came away from his Cantor Lectures with information of real use to them.

Measurements

In the field of electrical measurements Dr Fleming's most useful contribution was undoubtedly his improvement in 1885 of the Poggendorff arrangement for comparing the e.m.f's of cells. Later this became an indispensable tool in every electrical laboratory.

The idea was extremely simple—that of the introduction of a continuously adjustable resistance in series with the main potentiometer wire—thus enabling the potential drop in the wire to be adjusted to say 1000 divisions for one volt. In this way the so-called Poggendorff arrangement became direct reading.

In Fleming's original form it was cumbersome, and in addition its mercury cups far from portable.

Much of the credit of turning the idea into a commercial instrument was due to another pioneer—Colonel R. E. B. Crompton—that champion of direct currents. An accuracy in d.c. measurements of $\frac{1}{4}$ of one per cent was regularly obtainable by the potentiometer and this gave electrical designers a reliable means of testing the performance of their machines. As a direct result of the confidence in test figures, great improvements in design of dynamos were made so that British d.c. machines came rapidly to the front in efficiency.

Lamps and photometry

As we have seen, Dr Fleming from the early days of electric lighting was associated with the Swan Lamp Factory, and this aroused his interest in photometry. One of his earliest pieces of equipment was a photometric bench, and all his students had to make measurements of the candlepower of lamps and their efficiency. Some of his assistants became remarkably expert in this field—notably W. C. Clinton and Arthur Blok.

One of the advances made by Dr Fleming in the photometric field was that of the introduction of the large-bulb incandescent lamp having an aged filament as the source of light. As sub-standards of light such lamps are now to be found in most photometric laboratories.

The Royal Institution

From 1892 onwards Dr Fleming co-operated with Sir James Dewar for many years in researches on the effect of low temperatures on the electrical resistance of metals. The range covered was from +200 to −197°C. The coolants used were carbonic acid snow and ether, liquid ethylene, liquid oxygen or liquid nitrogen. During the early part of this period the universally used Dewar or vacuum flask was developed.

He was in great demand for the Christmas Lectures to Juveniles, giving them on four occasions. He also gave eight Friday evening discourses. His success in these as well as in his popular scientific lectures in the provinces was largely due to the meticulous care he took in devising the necessary apparatus for their illustration, and also because he did not overload his assistants.

The Edison effect

Reference was made earlier to Professor Guthrie's experiments on electrically charged bodies raised to a red-heat. Let us now consider the closely

allied subject of the uni-directional effect of the passage of electrical charges in a vacuum—the Edison effect.

Professor Guthrie had shown that an iron ball at a cherry-red temperature rapidly discharged negative electricity, but held positive charges at the same temperature. It is almost certain that Fleming assisted Professor Guthrie in these experiments in 1873.

Sixteen years later he gave a paper to the Royal Society in December 1889, on 'Electric discharge between electrodes at different temperatures in air and in high vacua', followed two months later by a Royal Institution Friday Evening Discourse on the same subject. In the interval he had been over to the U.S.A. and seen Edison in July 1884. He may, perhaps, although there is no actual evidence, have been shown the 'Edison effect' by its discoverer.

In his paper he outlined the following theory: 'From all parts of the incandescent loop, but chiefly from the negative leg, carbon molecules are being projected which carry with them, or are charged with, negative electricity. If now we introduce into the glass bulb a positively charged plate the negatively charged carbon molecules will be attracted, showing as an electric current when a wire from outside is connected to the insulated plate.'

From these experiments he deduces that the negatively charged molecules travel in straight lines. As he says, 'our molecular marksmen cannot shoot round a corner'.

In his 1896 Physical Society's paper entitled 'A further examination of the Edison effect in glow lamps' he speaks of 'a molecular shower of negatively charged atoms'. Later on in this same paper (experiment 27) he examined the case of the horse-shoe-shaped carbon filament which previously had been operated by a direct current but which was now rendered incandescent by means of an *alternating current* of 80 to 100 cycles per second, and found that it gave a rectified current in the plate at power frequencies.

Preparation for the advance

Now we must gather together various matters that probably prepared Fleming, although of course unconsciously, to make his major advance of the application of the valve for radio work.

Let us however see what the invention was. Fleming was the first to realize that a system of a hot filament with an insulated plate sealed into a bulb, might act as a rectifier for high frequency currents. He describes it as a 'sudden very happy thought'. So in October 1904 he asked his assistant the late G. B. Dyke to put the idea to the test—and it worked. Thus it was that

on a day in November 1904 Arthur Blok happened to see Fleming 'scudding down Gower Street' oblivious to all around him on his way to patent his invention.

We have seen that he had carefully studied both in 1883 and 1896 the Edison effect so that when the idea of a h.f. valve came to him he had the tool by him with which to put his idea to the test.

In 1896 he had shown that a beam of cathode rays could be focused by a current-carrying circular coil, if its axis coincided with the axis of the cathode rays. In 1889 he was appointed Scientific Adviser to the Marconi Wireless Telegraph Company—an appointment held for thirty years. It was in this capacity in 1900 that he was called upon to specify and test a power plant to be installed at Poldhu, Cornwall to produce the powerful electrical oscillations needed for the first transatlantic wireless telegraphy transmissions to Glace Bay, Newfoundland.

On 13 December 1901 Marconi first received a distinct signal—the letter S in the Morse Code, three dots.

In November-December 1900 Fleming gave an experimentally illustrated course of Cantor Lectures for the Royal Society of Arts, on 'Electrical oscillations and electric waves'. Finally he must have been engaged in gathering material for his forthcoming book of 670 pages entitled *The principles of electric wave telegraphy* when, late in 1904, he actually made his discovery.

A consideration of these subjects and the theoretical and experimental work involved brings home to one what an unique training Fleming had, which made it, one might almost say, a foregone conclusion that he should be the person to originate the idea of using the two-electrode valve as a rectifier for high-frequency currents.

Introduction of the 2-electrode valve

The application of this invention opened up a vast field of measurements of currents and voltages in radio telegraphy and telephony. Before this Rutherford had worked with the magnetic detector, whilst Branly, Lodge and Marconi were working with the coherer which was probably the most sensitive practical receiving detector, and it was universally used for the purpose of detecting electrical oscillations; but it was the advent of the two-electrode radio valve which enabled high-frequency measurements to be put on a firm foundation. For thus, for the first time, reliable quantitative radio measurements became possible. Needless to remark the old coherer was about as exasperating a tool for the purpose of making quantitative measurements as one could well imagine. In 1906 de Forest, two years after Fleming's

invention, added a third electrode—the grid separating the high-frequency circuit from that of the filament, and thus amplification became possible.

This addition enormously extended the value of Fleming's invention. But the great weight of scientific thought and legal opinion was that the de Forest invention was dependent on Fleming's prior fundamental invention.

In justice to Fleming it should be said that he disclaimed any credit for the introduction of the grid as used by de Forest, but only claimed the rectifying action for h.f. currents as his invention. Fleming first calls his invention an oscillation valve, later he used the term thermionic valve, and others called it a Fleming valve or a diode.

He took his full share in scientific discussions. As his deafness increased, he would take an assistant with him to make notes and thus was able to take part in discussions, which he did with his accustomed vigour.

At the age of 77 Fleming resigned his Chair and retired to Sidmouth, although this was not the end of his active life. Two years later the honour of knighthood was conferred upon him. He lived to the advanced age of 95.

The Television Society

For over fifteen years, indeed up to the time of his death, Sir Ambrose was president of the Television Society of London and often came up to address its meetings. This Society has done much to foster the growth of television amongst its members, by encouraging the reading of papers, usually experimentally illustrated, and by the publication of a monthly journal.

Fleming gave much support to the late J. L. Baird, that pioneer in television; a remarkable inventor combining vision with continuous pertinacity in spite of great difficulties. As Sir Edward Appleton has said 'There was an engaging simplicity about Baird's character. Baird deserves great credit for having pursued the objective of television in the home, with real single-mindedness of purpose, thereby encouraging others to join in the same contest.'

Although so much of his time was spent in lecture rooms and laboratories, Fleming took a keen interest in nature in all its aspects. He indulged in Alpine climbing, spent much time in water colour drawing. In addition he was an excellent photographer. His interest in photography dated from his early teens when he had made a camera in his own workshop.

From his earliest years Fleming was surrounded by religious influences. It was not, however, until he had reached late middle life that this strong Christian side became known.

Many, for instance, were surprised when he preached in the church of St Martin-in-the-Fields a sermon on the evidence for the resurrection. He spoke, too, for the Christian Evidence Society, and was generous to societies caring for the religious-social welfare of the poor.

He was twice married; his first wife was Miss Clara Ripley; she died in 1917. His second wife was Miss Olive Franks. They were married in 1933—she survives him. There were no children. It is interesting to know that it was through a concert at which she sang that they became known to one another.

Recognition of Sir Ambrose's work brought him many honours. He had been a Fellow of the Royal Society since 1892, was awarded the Hughes Medal 1910, and the Faraday Medal of the Institution of Electrical Engineers 1928.

Conclusion

Fleming's life work was devoted to science. His stressing of the importance of experiment combined with theory led to a great improvement in the training of engineers—not confined only to his own College.

He was fortunate to have reached his full powers at a time which coincided with the development of three great branches of electrical engineering, namely electric lighting, telephony and wireless. He contributed as we have seen much to all of these.

Looking back now over the period of thirty years from 1885 to 1915 to my mind the three outstanding professors of applied physics or of electrical engineering in England were W. E. Ayrton, Silvanus Thompson and Ambrose Fleming; W. E. Ayrton the fiery physico-electrical engineer, Silvanus P. Thompson, whose international outlook, combined with the persuasive charm of his teaching filled his lecture rooms to overflowing, and J. A. Fleming, whose direct style made him not only an ideal popular science lecturer, but also a great teacher both of students and practical engineers. All were Fellows of the Royal Society.

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